North Carolina
Department of
Transportation

Chapter 9 Culverts

January 2022

Revisions Sheet			
Page	**Old Section**	**New Section**	**Description**
-	-	-	• Entire Chapter revised to new format and minor grammatical changes made throughout • All references and links have been updated throughout Chapter
1	9.6	9.2	Moved Section – Economic Consideration; Re-numbered sections throughout
4	9.5.1	9.6.1	Removed last sentence
5	Appendix F – Item 3	9.6.1.1	Added new section – Culvert Avoidance and Minimization Design
6	9.5.1.3	9.6.1.4	• 2nd paragraph, 3rd sentence – added “for the 100-year event” to end • 2nd paragraph. 4th sentence – revised reference to “Chapter 8, Section 8.7.2.2” • Last paragraph revised
6	9.5.1.4	9.6.1.5	Revised entire section
7-12	Appendix F – Item 1	9.6.1.6.1	Added new section – Guidance for When to Use Sills/Baffles in Box Culverts
12-13	Appendix F – Item 2	9.6.1.6.2	• Added new section – Native Material Specification • 1st paragraph – revised to state that Native Material is preferred to be used for backfilling culverts
13-15	Appendix N	9.6.1.7	• Added new section – Anadromous Fish Passage • Technical Guidelines, 1st bullet – added US forest Service FishXing reference
16-17	Appendix H – Item 4	9.6.1.9	Added Tables 1 - 3
19	Appendix F – Item 4	9.6.2.1.2	Added new section – Aluminum Box Culvert (ABC) HEC-RAS Modeling Guidance
20	9.5.2.3	9.6.2.3	Entire section revised
21	-	9.7	Added new section – Pipe Liner Rehabilitation; Re-numbered sections
22	-	9.9	Added new section - References
24	-	9.10	Added new section – Additional Documentation

24	Appendix E – Item 2	9.10	Added link - Culvert Survey & Hydraulic Design Report
24	Appendix E – Item 3	9.10	Added link – Detour Structure Survey & Hydraulic Design Report
24	Appendix G	9.10	Added link – Pipe Data Sheet
24	Appendix H – Item 1	9.10	Added link – Pipe Material Selection Guide
24	Appendix V – Item 1	9.10	Added link – NCDOT Pipe Liner Manual
24	Appendix V – Item 2	9.10	Added link – NCDOT Pipe Liner Special Provision
24	Appendix V – Item 3	9.10	Added link – Grouting Host Pipe Special Provision
24	Appendix V – Item 4	9.10	Added link – Invert Paving Special Provision
25-28	Appendix H – Item 3	9.10	Added table – Table 210 Engineering Field Handbook Minimum and Maximum Fill Heights over Pipes

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9.1 Introduction

In this chapter, a culvert is defined as a hydraulic conduit that conveys flow through a roadway embankment. The most used culvert shapes are circular, rectangular, elliptical, and arch. They range in size from large multiple barrel culverts to a single 18-inch diameter pipe, which is the minimum size for cross-drainage. The design process for culverts involves economic consideration, design documentation, data collection, hydrologic analysis, hydraulic analysis and design.

9.2 Economic Consideration

When more than one alternate will satisfy all control factors for a site, the evaluation and selection of an optimal alternate should include a cost analysis to ensure that the selected alternate will be the most cost effective over the structure's life cycle.

9.3 Design Documentation

A Culvert Survey and Hydraulic Design Report (CSR) is required for any structure that is on a FEMA-regulated stream or has a hydraulically effective total waterway opening of thirty square feet or more, excluding any area of the culvert that is buried below the streambed. For culverts with a waterway opening of less than 30 square feet, summarize the design data on the Pipe Data Sheet. All design data in the CSR or Pipe Data Sheet should be based on either HEC-RAS ((USACE 2021) (USACE 2021) (USACE 2021) (USACE 2021)) hydraulic models or HDS-5/HY-8 ((FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012), (FHWA 2021)) results, as applicable.

Documentation on the CSR should include, but is not limited to, the following:

1. Plot and label the proposed structure in plan and two profile views -- along roadway alignment and along the structure alignment. Note the roadway centerline station, skew, and grade point elevation. Specify the box culvert dimensions in terms of the number of barrels at a given span dimension by rise dimension (e.g., two at ten feet by six feet RCBC). The drawing scales in the CSR are typically 1 inch = 50 feet horizontal and 1 inch = 10 feet vertical. Limit information to that which is pertinent to the structure sizing and location.
2. Show centerline invert elevation (or top of footing elevation for "bottomless" culvert) and slope. Note: determine precise length and end invert elevations by Structures Management Unit.
3. Show normal, design and 100-year water surface elevations on all views.
4. Enter all required data for selected structure as completely as possible on the CSR. Enter "N/A" in data fields which are not applicable. Use the Additional Information

and Computations section to document pertinent important design information not covered elsewhere in the CSR.
5. Note software and versions used for computations. Include supporting computer data files (e.g., HEC-RAS, HY-8, HDS-5) and summaries in all project documentation.
6. Complete the performance table for the proposed structure with a comparison to the natural and existing conditions (if applicable) stage-discharge relations.

9.4 Data Collection

Assemble information gathered during the pre-design study (see Chapter 3) and field survey (see Chapter 5) relative to each particular crossing or all crossings in general. Prior developing the final design, follow the following guidance to begin preparing the appropriate documentation.

9.4.1 Culvert Data – Profiles Views

There are two profiles that are included in the CSR: the longitudinal profile of the roadway showing the floodplain section and the roadway vertical alignment grades for both the existing and proposed conditions. On this profile, the culvert opening and natural ground are typically depicted at the upstream face. Label for clarification if a different convention is used. The other profile is along the centerline of the structure, depicting the layout of the culvert relative to the stream.

1. <u>The longitudinal profile along the roadway alignment should include:</u>
   - natural ground lines upstream, and downstream, if significantly different
   - channel base and banks
   - roadway grade for both the existing and proposed conditions
   - existing and proposed culverts
   - water surface elevations, as of date of survey, and normal, if different
   - 100-year floodplain limits
   - historical flood elevations, including dates of occurrence, and estimated frequency
   - utility elevations
   - controlling backwater feature elevations
   - buildings: finished floor elevations and lowest adjacent grade, roadways, driveways, other drainage structures, overtopping controls, etc.
   - general classification of stream bed and bank materials (clay, sand, gravel, etc.).

   The low point of the roadway profile is the point at which roadway overtopping will occur. It is prudent to note this location and elevation on the profile.

2. <u>The centerline profile of the structure should include:</u>
   - stream bed
   - top of banks

- existing and proposed roadway cross-sections
- existing and proposed culverts
- normal water surface (vegetation line, also known as ordinary high water) profile
- historical flood levels
- controlling feature elevations properly positioned along the profile
- rock line, if identified

The centerline profile's purpose is to establish the length and inverts of the proposed culvert by superimposing the culvert barrel on the roadway cross section and stream bed profile. Note if an existing culvert is to be retained and extended, and include its type, condition, top slab and interior web thickness, slope, and opening.

Plot any additional stream details utilized for design or needed for channel realignments on the CSR. Note: These also need to be included on details sheets in the roadway plans to ensure they will be followed and utilized during construction.

9.4.2 Culvert Data – Plan View

Include the following information on the plan view:

- natural features: stream/water edges, banks, ground cover, wetland boundary, buffers
- manmade features: buildings, houses, roads, driveways, existing drainage, utilities, etc.
- proposed roadway and fill slope limits, retaining walls, easements, right-of-way
- proposed drainage structures, channels, rip rap, etc.
- Floodway Boundaries designated and regulated by FEMA
- other information, such as flow direction, north arrow, survey line and stations, land cover, etc.

9.4.3 Cross Pipe Data

For any culvert with total waterway opening of less than 30 square feet and on a stream that is not regulated by FEMA, summarize the design data on the Pipe Data Sheet. The Design Engineer must also reference the drainage plans for topographical and proposed layout information.

Size driveway pipes in roadside ditches to convey the same discharge as that for which the ditch is designed (see Chapter 11 Roadside Ditches and Channels). Generally, for driveway pipes, design documentation on Pipe Data Sheets is not required. However, the Design Engineer may elect to do so for those which are 48 inches in diameter or larger.

9.5 Hydrologic Analysis

The hydrologic analysis for a culvert differs from that for bridges primarily due to the smaller drainage areas involved. However, the analysis may be similar for larger culverts. Refer to Chapter 7 Hydrology for more guidance regarding hydrologic analysis.

The hydrologic analysis for culvert design entails:

1. Determination of the drainage area for the site
2. Developing flood discharges
3. Q_d – design discharge, as listed in Chapter 7, Table 1
4. Q_{10} – 10-year discharge
5. Q_{100} – 100-year discharge
6. Q_{ot} – overtopping discharge, if less than Q_{500}
7. Q_{500} – 500-year discharge, if less than Q_{ot}

Use the Base Flood discharge if the stream crossing is in a FEMA Flood Insurance Study (FIS) to assess the flood impact and compliance with FEMA's NFIP. An alternate analysis may be warranted if an error is found in the FEMA hydrologic analysis. The Design Engineer may request a review from NCFMP and/or the State Hydraulics Engineer for guidance and approval of an alternative for determining the discharge rates.

1. Record pertinent hydrologic analysis data on the CSR, such as land use change, stream gage, physical changes (dam, impoundment, etc.).
2. Provide a performance table of the natural, existing (if applicable), and proposed conditions flood elevations at the upstream toe section for the following discharges: Q_{10}, Q_d, Q_{100}, and Q_{500} (or Q_{ot}, if less). Clearly identify the location of the flood elevations that are compared
    - For example, "at section 1001, 15 feet upstream of culvert inlet"
3. Include details and typical cross sections inside and outside the culvert that depict the design features necessary to mimic the natural channel, such as back fill of native bed materials, benches, sills and baffles, energy dissipators, etc.

9.6 Hydraulic Analysis and Design

9.6.1 Design Criteria

The first step in developing a CSR is to establish the applicable design criteria and constraints prior to commencing actual structural sizing and location. Avoid or minimize adverse impacts to the natural and human environments to the maximum extent possible. A sound culvert design should include consideration for proper location and alignment, adequate opening, safety of the traveling public, debris loading, channel stability, sediment transport, post-construction maintenance, outlet channel protection, life cycle of material, etc.

9.6.1.1 Avoidance and Minimization Measures

When designing a culvert, ensure that the following avoidance and minimization design criteria have been evaluated and implemented as much as possible:

- Proposed culvert slope is consistent with the existing stream slope. Proposed low flow dimensions through the culvert are consistent with the existing low flow channel dimensions in the stream. Alternating low flow sills/baffles may be required to achieve this.
- Proposed low flow velocities through the culvert are consistent with the existing low flow velocities in the stream.
- Proposed culvert is appropriately buried such that the bed material will be retained throughout the culvert length. The use of alternating low flow sills/baffles should be evaluated based on culvert slope, bed material and stream stability.
- The dimension and profile of the stream above and below the culvert should not be modified by widening the stream channel or by reducing the depth of the stream in the vicinity of the culvert. Establishing a low flow floodplain bench should be evaluated at the inlet and outlet of multiple barrel culverts.
- Minimize culvert length as much as possible.
- Culvert alignment avoids sharp bends at the inlet and outlet to avoid bank erosion at the inlet and outlet. Stream realignment and/or armoring may be needed to improve culvert alignment and/or to mitigate potential stream bank erosion. Minimize the amount of stream work to be done up and down stream.

9.6.1.2 Material Selection

The selection of a culvert may vary depending on its location, subsurface materials, and constructability. The most used structures are reinforced concrete box culverts (RCBC), reinforced concrete pipes (RCP), corrugated steel pipes (CSP), and corrugated aluminum alloy pipes (CAAP). Of those structures, the most common shapes are rectangular, circular and arch. Depending on the site constraints as well as the size and type of structure that are needed, follow the applicable guidance below:

- Pipe culverts:
  Follow the guidance prescribed in the NCDOT Pipe Material Selection Guide, Chapter 5 of the NCDOT Roadway Design Manual (NCDOT 2021), and Standard No. 300.01 “Method of Pipe Installation”, NCDOT Roadway Standard Drawings (NCDOT 2012) for material selection, associated fill-height limitations, and pipe installation methods.

- Box culverts:
  Box culverts are typically comprised of reinforced concrete, either precast or cast in place. There are also large metal structures, arches and box shapes, with and without bottom plates that can be considered for sites requiring large opening and/or spans. Develop the culvert design based on a four-sided, cast-in-place reinforced concrete box design unless site constraints dictate other culvert type. The State

Hydraulics Engineer should review and approve any culvert design alternates to the approved CSR proposed by the contractors during construction. NCDOT Pipe Material Selection Guide and Section 9.10 provides the maximum fill height tables.

9.6.1.3 End Treatment

Headwalls are generally used on the inlet end of a 36-inch diameter pipe culvert or larger. Maximum height of headwalls shall be one foot above the pipe structure. Neither Mechanically Stabilized Earth (MSE) nor Modular Block walls are considered appropriate for culvert headwall application. If the culvert is 150 feet or more in length and functions in inlet control, consider an improved inlet design. The outlet end of a pipe does not require an endwall, unless an exception is warranted, such as limited right-of-way, buoyancy on metal pipes, eroded channel, pipe-disjoint potential, etc. For guidance on end treatment of parallel pipes, refer to Section 5-20 of the *Roadway Design Manual* (NCDOT 2021).

9.6.1.4 Allowable Headwater

The allowable headwater elevation is established based on an evaluation of flood elevation, freeboard, upstream structures, and proposed roadway elevations. Measure the headwater depth from the design flood elevation to the invert of the inlet of the culvert, generally not exceeding the lowest upstream shoulder (overtopping) point elevation of the roadway or an elevation about twenty percent higher than the height of the culvert, whichever is lower. For routes functionally classified as Major Arterials (Interstates and primary routes), a minimum freeboard of 1.5 feet is recommended. Other factors to consider include impacts to adjacent properties, potential damage to the culvert and roadway, level of service, cost, safety, channel stability, floodplain regulations, available detour routes, etc.

For a culvert replacement, the headwater of the proposed culvert should not exceed that of the existing culvert during the design flood and 100-year events. An exception may be allowed when in a rural area with no appreciable flood damage impact to the floodplain or adjoined properties. For a road project on new location, the new culvert should not result in more than one foot of backwater over the natural condition for the 100-yr event. Also refer to guidance regarding backwater in Chapter 8, Section 8.7.2.2.

FEMA's Base Flood Elevation (BFE) should be used as the allowable headwater elevation to size the culvert if the replacement or new culvert is on a FEMA-regulated stream. If the proposed design would result in a change in BFE, the Design Engineer should obtain a Conditional Letter of Map Revision (CLOMR) or State Floodplain Compliance (SFC) approval. See Chapter 15 for additional guidance.

9.6.1.5 Multiple Barrels

Multiple barrels often need to be considered, such as when roadway embankment is low in height, or the channel is shallow and wide. The recommended minimum barrel dimension for a new box culvert is six feet span (width) by seven feet rise (height). This allows for six feet of vertical clearance inside a box culvert for inspection and maintenance, presuming the floor is buried one foot below the stream bed. Exceptions to this minimum size specification should be approved by Hydraulics Unit. An existing culvert with smaller dimensions does not necessarily warrant replacement of the culvert. A multiple barrel box culvert is more economical than a single barrel of the same hydraulic conveyance, due to its structural requirements for the top slab member. When the total width of the multiple barrels is larger than that of the channel, evaluate the need for barrels to be set at different elevations to minimize head cut, channel instability, and aggradation.

9.6.1.6 Sills and Baffles

Sills are vertical walls attached to the culvert bottom, placed at both the inlet and outlet of the culvert to mimic the natural channel opening.

Baffles are vertical walls attached to the culvert bottom placed at designed intervals inside the culvert to maintain a low flow channel for aquatic organism passage.

One barrel passes normal flow and the others collect sediment and debris. Normally, all multiple barrels are built on the same elevation. The low-flow barrels are buried one foot below the streambed and aligned with the natural channel; other barrels are installed with engineered sills to mimic the existing channel width.

The force of the high floods may result in a natural flushing of sediment and debris out of the barrels, depending on the available headwater, vegetation growth, backwater from the receiving stream, etc. Investigate the cause and source of sediment accumulation if a heavy accumulation of sediment is found in the barrels of an existing culvert and consider mechanically removing the sediment. If site conditions clearly indicate that excess sediment inside the barrel would be flushed out of the barrel in high water events, perform the hydraulic analysis based on the total clear width and height of the barrel (excluding the buried portion) being available for flow conveyance. Conversely, if a culvert is in an aggregated channel and no stream restoration is planned, do not assume the total clear width and height to be effective for flow conveyance in the design. Sills are normally placed in each barrel of multiple barreled culverts to retain the native material in the culvert as well as to minimize head cutting.

9.6.1.6.1 Guidance for When to Use Sills / Baffles in Box Culverts

This guidance is intended primarily for reinforced concrete box culverts but may also be applicable to larger aluminum box culverts, corrugated steel pipes and corrugated steel pipe arches. Refer to Section 9.6.1 for criteria to evaluate in culvert design. Refer to Section 9.6.1.6.2 for material to be used to backfill sills/baffles.

Sills are vertical extensions attached to the culvert bottom placed at the inlet and outlet of the culvert. Baffles are vertical extensions attached to the culvert bottom placed at designed intervals inside the culvert beyond the sills located at the inlet and outlet. Sills can be used to retain the native material in the culvert as well as to help prevent head cutting. Sills may be used at the inlet and outlet of the higher flow barrels of multiple barreled culverts to help maintain the natural stream width and depth through one or more of the barrels. Baffles and sills can be used together to help:

- retain native material in culverts on steeper slopes
- slow velocities in very steep culverts
- create a low flow channel in the culvert by varying the dimensions (height and width) of the sills/baffles.

See Figure 1 below for example of sill/baffle detail:

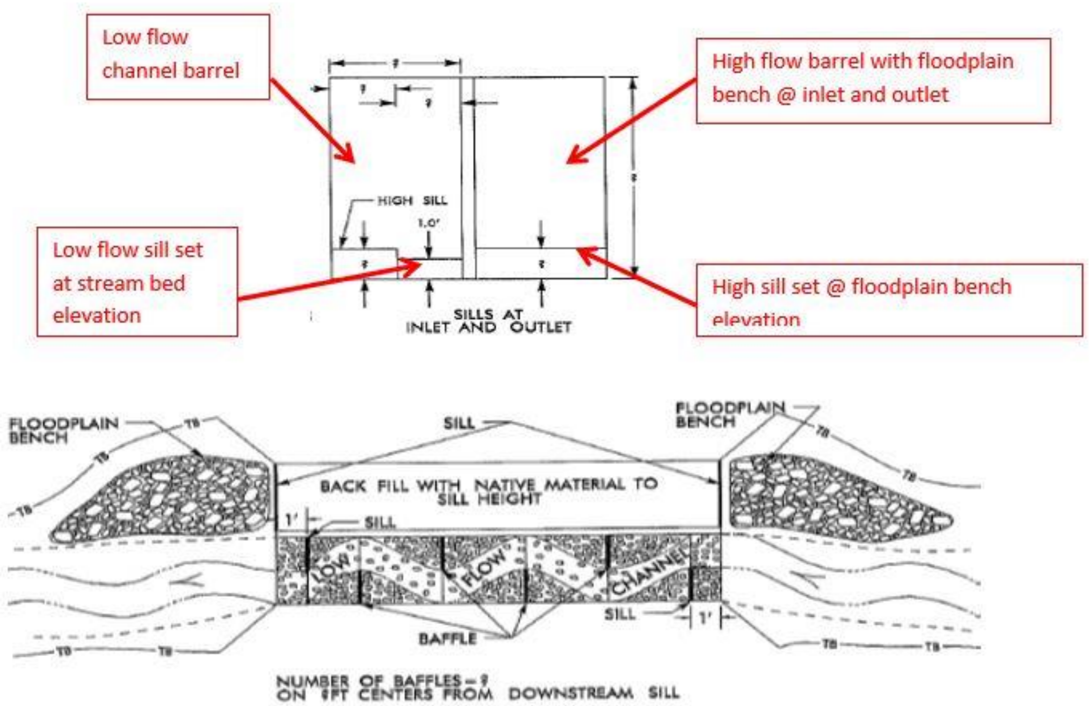

Figure 1. Sill/Baffle Detail

Baffles and sills do not have to be alternating as shown in the above detail. Evaluate each stream crossing to determine the appropriate design and evaluate the need for using sills and baffles based on factors such as culvert width, stream width, culvert slope, stream slope, culvert length, stream stability, bed material, propensity to head cut and the need for floodplain benches. The following criteria may be used as a guide in determining when to use sills/baffles in box culverts.

Evaluate Culvert Width vs. Stream Width

If possible, design the culvert barrel width to match the stream's low flow width. For new multi-barrel culverts, only one barrel should convey the stream at low flow conditions. Look up and down stream of an existing structure to determine the stream's low flow width, since the width of the stream close to the existing structure is in many cases wider. If the culvert barrel width when compared to the existing streams low flow width is such that the stream's low flow width and depth cannot be maintained through the culvert, sills and baffles will be required to establish a continuous low flow channel through the culvert barrel. The height of the sills and baffles should vary across the width of the culvert barrel to provide a continuous low flow channel through the culvert similar to the natural stream's low flow (thalweg) width and depth. See Figure 2 for reference. The sills and baffles should be spaced throughout the length of the culvert to hold the bed material and maintain adequate flow depth during low flow conditions. The culvert should be buried a minimum of one foot and backfilled with native material. The top of the low flow sills/baffles should match the stream bed elevation in the low flow channel.

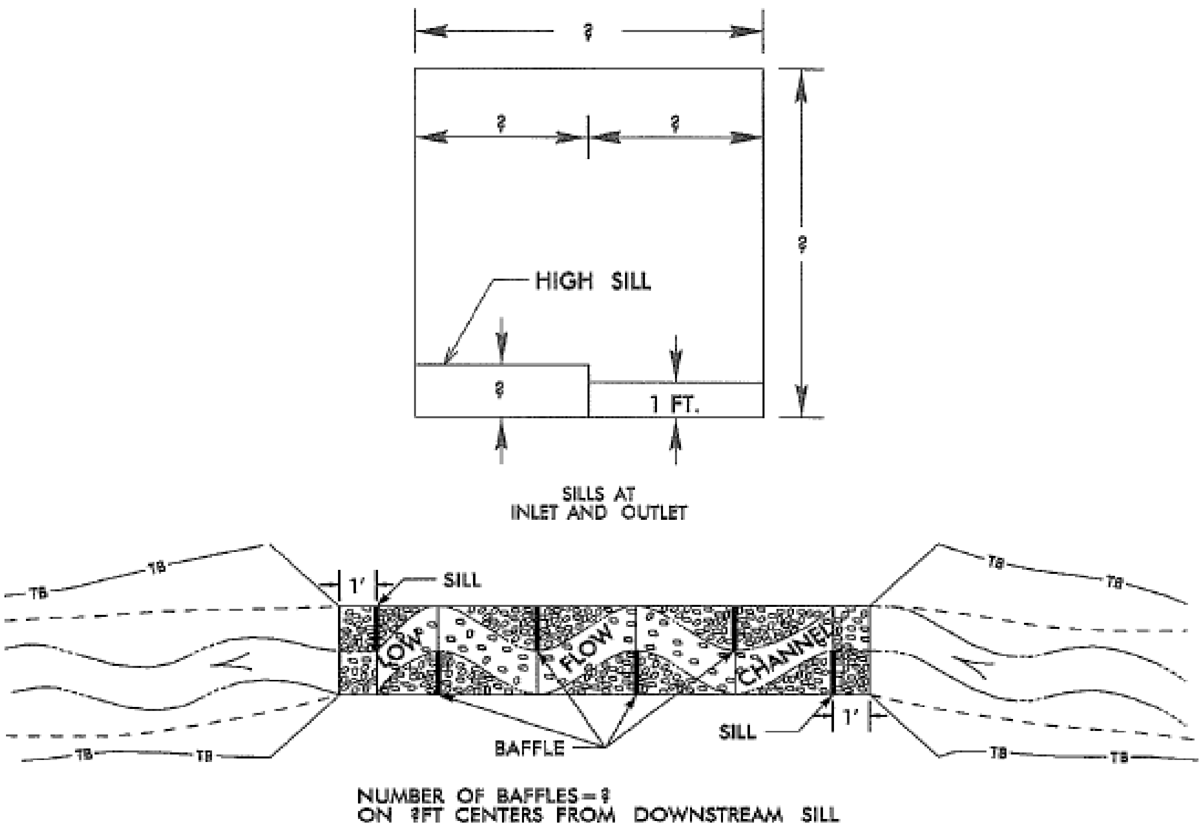

Figure 2. Sills and Baffles Used to Create a Low Flow Channel Through Culvert

Evaluate Culvert Slope vs. Stream Slope

Evaluate the culvert slope/stream slope if the culvert barrel dimensions are such that the stream's low flow width and depth can be maintained through the culvert, to determine if sills and or baffles are required to help retain the bed material in the culvert. In this case, the dimensions of the sills/baffles do not need to vary since the width and slope of the culvert will maintain the stream's low flow width and depth. The purpose of the sills and baffles is to retain bed material in the culvert, provide an approximate low-flow stream shape to assist in aquatic organism passage, and to help prevent head-cutting when culverts inverts are buried below the stream bed. The following general guidance may be used when determining the need for sills and baffles based on culvert slope/stream slope (stream stability and bed material should be considered also as noted below):

- Sills and baffles are generally not required if the culvert slope/stream slope is less than 1%. Bury the culvert a minimum of one foot below the stream bed and allow it to fill in on its own. If the stream is very unstable and the stream slope varies up and downstream of the culvert, evaluate if sills and baffles should be used. Typically, unstable streams with less coarse bed materials (sand and silt) may require the use of sills and baffles at slopes less than 1%.
- Sills and baffles are generally required if the culvert slope/stream slope is between 1% and 2%, to help retain the native material in the culvert barrel. The culvert should be buried a minimum of one foot below the stream bed with sills and baffles. The sill and baffle height should match the burial depth and they should be backfilled with native material. If the stream is very stable and if the stream slope is constant throughout the length of the culvert as well as up and downstream of the culvert, sills and baffles may not be required. Typically, stable streams with coarser bed materials (gravel, cobbles and boulders) would be more likely to not require sills and baffles until slopes above 2% are reached.
- Sills and baffles are required if the culvert slope/stream slope is greater than 2%, to help retain the native material in the culvert barrel. The culvert should be buried a minimum of one foot below the stream bed with sills and baffles. The sill and baffle height should match the burial depth and they should be backfilled with native material.

Floodplain Benches

Figure 3. Culvert with Floodplain Bench

Sills should be used for multiple barrel culverts where high flow barrels are required with floodplain benches at the inlet and outlet. Place the sills at the inlet and outlet of the high flow barrel(s) and backfill the barrel(s) to the sill height with native material. The sill height at the inlet and outlet of the high flow barrel should be above the low flow normal water surface elevation. See Figure 4 for reference. Figure 4 shows a multi barrel culvert with one barrel that matches the low flow stream width and the other barrel with sills and floodplain benches at the inlet and outlet. The low flow barrel for this detail matches the streams low flow width and does not require sills to retain the bed material. Figure 3 is a picture of a multiple barrel culvert with floodplain bench.

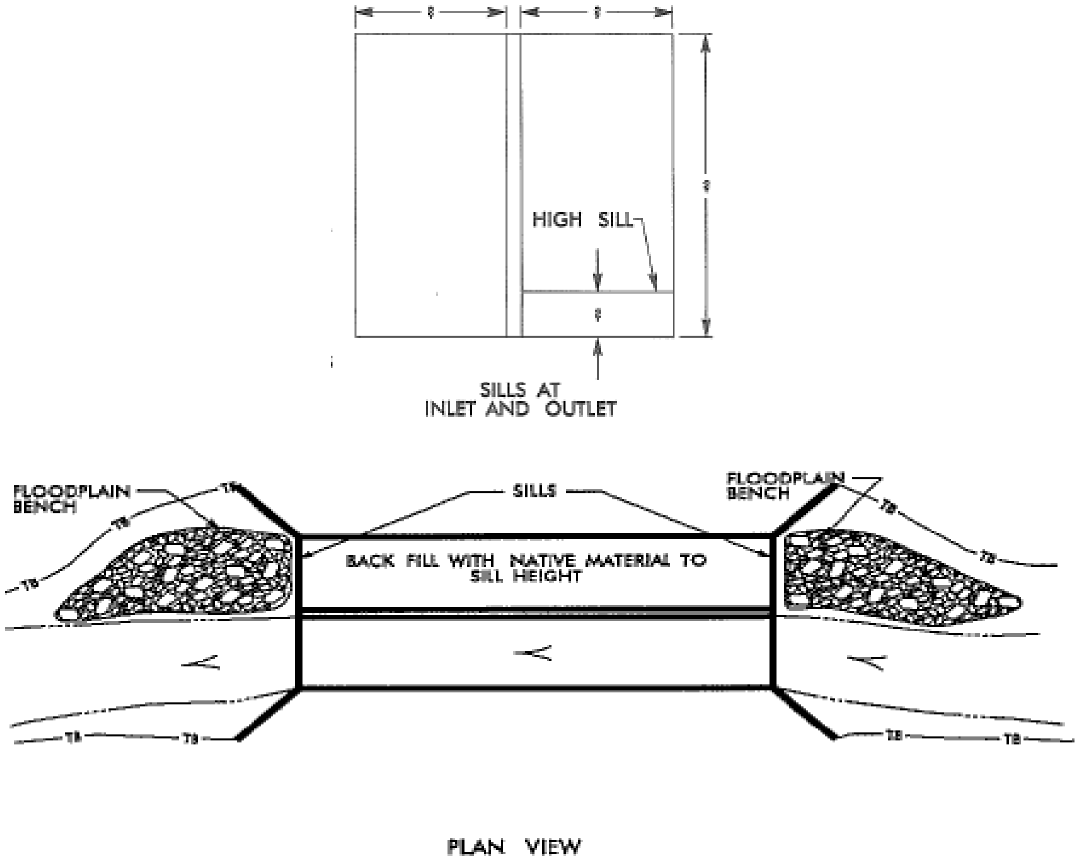

Figure 4. Sills in High Flow Barrel with Floodplain Bench

Wide single span culverts, such as aluminum box culverts, may require floodplain benches at the inlet and outlet to maintain the natural stream width up and downstream of the culvert. The sills for these types of structures should be detailed to provide a low flow notch to match the stream's low flow width. See Figure 5 below for example detail:

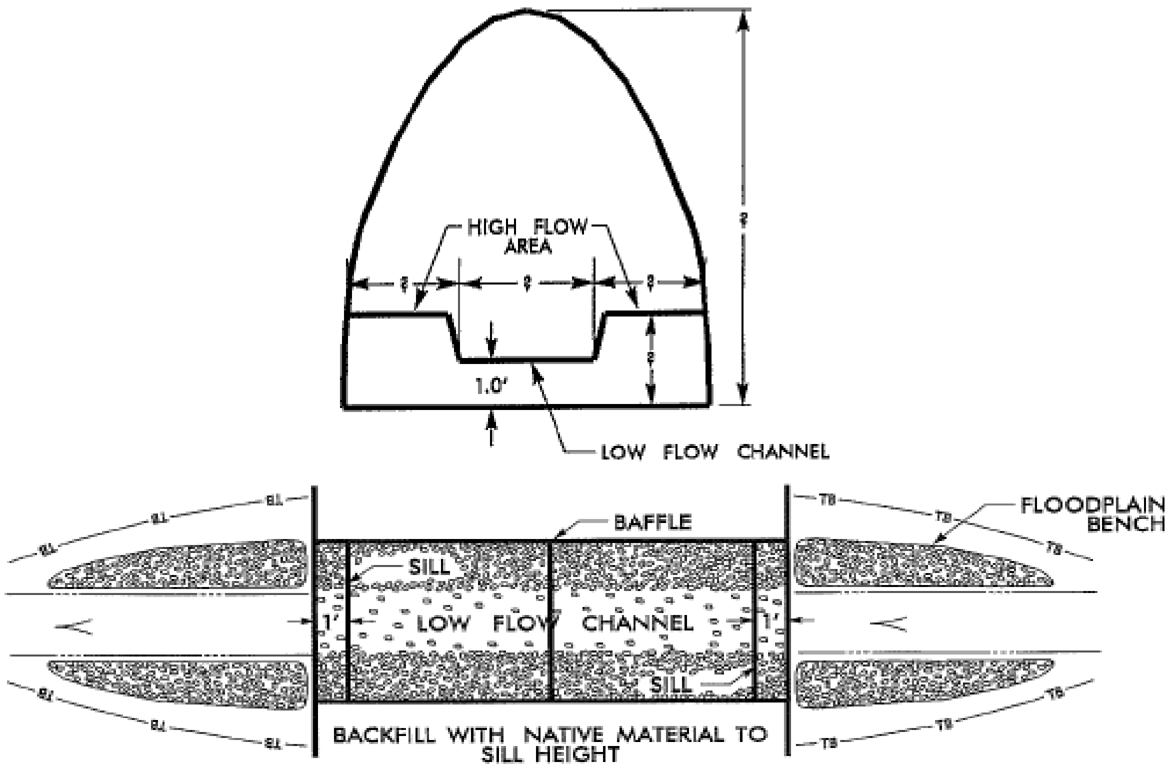

Figure 5. Sill with Notch on Wide Single Span Culvert with Floodplain Bench

Sill Spacing

Sills/baffles in culverts are typically spaced at approximately 25-foot intervals. On slopes steeper than 2%, the spacing may be shortened to an interval length equal to 0.5 feet divided by the slope of the culvert or as deemed appropriate. Ten feet is typically the minimum spacing used. Space the sills to hold the bed material and maintain adequate flow during low flow conditions.

Detail the dimensions, locations and spacing of the sills/baffles on the CSR (or on a detail to be included with the CSR) and note which culvert barrels should be backfilled with native material.

9.6.1.6.2 Native Material Specification for Backfilling

Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Normally, native material is preferred to be used for backfilling culverts. Pay for native material as incidental to the culvert construction. Additional rip rap, if needed, will be paid at the contract price of rip rap or negotiated price, if not already in the contract. Detail the dimensions, locations and spacing of the sills/baffles on the CSR (or on a detail to be included with the CSR) and note which culvert barrels should be backfilled with native material.

The following note should be added to the CSR when backfilling the culvert with Native Materials between sills and/or baffles:

- Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Only material that is excavated from the stream bed may be used to line the low flow culvert barrel. Rip rap may be used to supplement the Native Material in the high flow culvert barrels. If using rip rap to line the high flow culvert barrels, place Native Material on top to fill voids and provide a flat surface for animal passage. Native Material is subject to approval by the engineer and may be subject to permit conditions.

The above note may be modified as follows if there is no high flow culvert barrel:

- Native Material consists of material that is excavated from the stream bed at the project site during culvert construction. Native Material is subject to approval by the engineer and may be subject to permit conditions.

The above note may be modified as follows if native material is only required in the high flow culvert barrel

- Native Material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction. Rip rap may be used to supplement the Native Material in the high flow culvert barrels. If using rip rap to line the high flow culvert barrels, place Native Material on top to fill voids and provide a flat surface for animal passage. Native Material is subject to approval by the engineer and may be subject to permit conditions.

Provide the following backfill note on the CSR:

"The Engineer, in consultation with DEO staff, shall review all material to be used as backfill prior to conducting the backfill activity. Backfill shall consist of native material only unless the Engineer, in consultation with DEO staff, determines that (1) the native material is unsuitable, or (2) additional material is required to supplement the native material. The chosen backfill material shall not have adverse effects to aquatic life, aquatic life passage, or water quality. Native material consists of material that is excavated from the stream bed or floodplain at the project site during culvert construction."

9.6.1.7 Anadromous Fish Passage

Anadromous Fish are a valuable resource, and their migration must not be adversely impacted. This document provides guidance to NCDOT to ensure that replacing existing and new highway stream crossing structures will not impede the movement of Anadromous Fish.

Applicable when:

- project is in the Coastal Plain region. Refer to NCDOT Project Atlas Site (NCDOT 2021) for physiographic boundary region
- perennial and intermittent streams are delineated on most recent USGS 7.5-minute quadrangle maps

General Guidelines:

- Project design and scheduling should avoid the necessity of instream activities during the Spring migration period, which defined as the time between February 15 and June 15. In areas where the shortnose sturgeon may be present, the Cape Fear, Brunswick and Waccamaw Rivers, Spring is defined as February 1 to June 15.
- Bridges and other channel spanning structures are preferred where practical.

Technical Guidelines:

- In all cases, the width, height and gradient of the proposed opening shall be such as to pass the average historical spring flow without adversely altering flow velocity. Spring flow should be determined from gage data if available. In the absence of this data, bankfull flow can be used as a comparative level. For fish swimming limitations use US Forest Service FishXing swim speed table (USDA Forest Service 2012) or USACE's *Fisheries Handbook of Engineering Requirements and Biological Criteria* (USACE. Bell, Milo C. (author) 1986)
- The invert of box culverts must be at least one foot below the natural stream bed. For smaller pipes, follow the burial tables shown in Table 1 or Table 2, contingent upon the project being located in a CAMA County.
- Crossings of perennial streams serving watersheds greater than one square mile shall provide a minimum of four feet of additional opening width, measured at spring flow elevation, to allow for terrestrial wildlife passage.
- In stream footings for bridges will be set one foot below the natural stream bed when practical.

At a minimum, provide the following information to facilitate resource agency review for crossing sites:

- plan and profile views showing the existing and proposed crossing structures in relation to the stream bank and bed
- average historical spring flow (or bankfull flow) for the site
- how the proposed structure affects the velocity and stage of the spring flow (bankfull)
- justifying any variance from the guideline recommendations

For additional information and guidance regarding accommodations to facilitate aquatic organism passage and habitat, refer to FHWA *Culvert Design for Aquatic Organism Passage* HEC-26 (FHWA. R.T. Kilgore, B.S. Bergendahl and R.H. Hotchkiss (authors)

2010). The NCDOT Project ATLAS website (NCDOT 2021) also includes the distribution of potential anadromous fish habitat streams in North Carolina.

9.6.1.8 Length and Alignment

Culverts must generally be long enough to accommodate the proposed roadway section with a 2:1 fill slope, or flatter, from shoulder point to the top of pipe or top of roof slab of box (not headwall). Align the culvert with the natural channel with minimum transitions made between the opening ends of the culvert and natural channel to the extent possible. When significant channel realignment is required other than minor alignment adjustments at the inlet and outlet, utilize a natural channel design (see Chapter 11). In general, pipes and box culverts should be aligned with the existing channel. The skew that is referenced in the CSR is defined as the angle measured clockwise from the centerline roadway alignment in the direction of progressing stations (i.e., “line ahead”) to the centerline of the culvert. Skew the culvert to align with the direction of flow. If a culvert extension requires a bend to better align with the stream, the existing culvert should be extended a minimum of five feet along the existing structure alignment before applying the bend. Note that an added bend in the culvert will incur an energy loss, which must be accounted for in the hydraulic computations. Avoid bends in culverts if the potential for debris to become lodged is apparent.

9.6.1.9 Slope and Sediment

Construct pipe or box culverts on slopes that are consistent with the existing channel to minimize channel aggradation or degradation. Most culverts are constructed on slopes that are less than ten percent. For concrete pipes on steep slopes, a junction box and/or an end wall is recommended at the outlet. Culverts on steep slopes may result in major maintenance issues, such as deformation from negative pressure, seepage, joint separation, outlet scour hole, sink hole, etc.

Set the inverts of a culvert at an appropriate depth below the natural bed to ensure the passage of aquatic organisms. This depth may range from a few inches for small pipes to one foot for large culverts. All box culvert inverts should be set a minimum of one foot below the natural bed, unless extending an existing culvert that is not buried. If shallow, non-erosive bedrock is found three feet or less below the streambed, consider proposing a bottomless (“three-sided”) culvert. Confirmation from the Geotechnical Unit on the depth of the rock line along the length of the proposed culvert is required. Refer to the tables below for specific burial depth guidance.

Table 1. Pipe Burial Depths - Non-CAMA Counties

Jurisdictional Streams					Non-Jurisdictional Streams			
Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial		Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)	% Burial
18	3.6	0.3	20		18	Not Req'd	-	-
24	4.8	0.4	20		24	Not Req'd	-	-
30	6.0	0.5	20		30	Not Req'd	-	-
36	7.2	0.6	20		36	Not Req'd	-	-
42	8.4	0.7	20		42	Not Req'd	-	-
48	9.6	0.8	20		48	Not Req'd	-	-
54	12.0	1.0	-		54	Not Req'd	-	-
60	12.0	1.0	-		60	Not Req'd	-	-
66	12.0	1.0	-		66	12.0	1.0	-
72	12.0	1.0	-		72	12.0	1.0	-

Table 2. Pipe Burial Depths - CAMA Counties

Jurisdictional Streams				Non-Jurisdictional Streams		
Pipe Diameter (in)*	Burial Depth (in)	Burial Depth (ft)		Pipe Diameter (in)	Burial Depth (in)	Burial Depth (ft)
18	-	-		18	Not Req'd	-
24	-	-		24	Not Req'd	-
30	-	-		30	Not Req'd	-
36	12.0	1.0		36	Not Req'd	-
42	12.0	1.0		42	Not Req'd	-
48	12.0	1.0		48	Not Req'd	-
54	12.0	1.0		54	Not Req'd	-
60	12.0	1.0		60	12.0	1.0
66	12.0	1.0		66	12.0	1.0
72	12.0	1.0		72	12.0	1.0
*Since the minimum bury depth is 12", a 36" diameter pipe is considered the smallest practical pipe to use.						

Table 3. Minimum Equivalent Pipe Diameter

Buried Pipe Diameter (in)	Equivalent Inlet Ctrl. Pipe Diameter (in)	Equivalent Outlet Ctrl. Pipe Diameter (in)
18	15	12
24	18	15
30	24	18
36	30	24
42	36	30
48	42	36
54	48	42
60	54	48
66	60	54
72	66	60

Most culverts do not encounter sedimentation or head cut problems if they conform to and are aligned with the natural channel. A stable channel is expected to balance erosion and deposition of sediment, achieving equilibrium over time. If a culvert is in a degrading channel, it may result in upstream head cutting and scour holes downstream.

Examples are entrenched downstream channel, urbanized channelization, channel straightening, etc. If a culvert is in an aggrading channel, it may accumulate sedimentation inside and outside the barrel, which may require periodic channel and culvert cleanout to maintain design conveyance. Examples are erosion from development in the watershed, flow blockage, ponding downstream, etc. If the culvert and/or channel are heavily silted, account for the resulting reduction in hydraulic conveyance, unless the excessive sediment is proposed to be removed from both the channel and the culvert and measures provided to prevent recurrence of the heavy siltation. Use HEC-RAS to perform sediment transport and mobile bed computations to determine the available hydraulic conveyance of the culvert during the flood event of interest.

9.6.1.10 Tailwater

The computed normal water depth for each discharge level being evaluated generally establishes the tailwater depth. For culverts which are not on FEMA-regulated streams, determine tailwater depth by a simple single section normal depth calculation, such as that provided in HY-8 (FHWA 2021). For those on FEMA-regulated streams, determine tailwater using HEC-RAS (discussed below). Effects of downstream controls and constrictions must also be considered. Document tailwater calculations in the Additional Information and Computations section of the CSR or on the Pipe Data Sheet, as applicable.

9.6.2 Culvert Design

Culverts which are not on FEMA-regulated streams may be analyzed using the FHWA's *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5* (HDS-5) (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) methodology or by HEC-RAS ((USACE 2021) (USACE 2021) (USACE 2021) (USACE 2021)), as appropriate. HEC-RAS should be used if proposing to replace a bridge with a culvert or in situations where a more detailed step backwater analysis is needed.

Special design situations that may affect the load bearing of the structure should be coordinated with the Structures Management Unit as early as possible in the design process. Examples are pipe connecting to the culvert, traverse utility lines inside or adjacent to the culvert, "Y" culvert junction, bend in culvert, etc.

9.6.2.1 HEC-RAS

Use HEC-RAS when any of the following apply:

- stream is in a regulated FEMA flood zone
- there is a need to assess flood impact by the proposed crossing to structures on adjoining properties
- establishing water surface elevations (by step backwater analysis) for a culvert design

- determining backwater caused by a bridge for the existing and proposed conditions

9.6.2.1.1 General Modeling Guidance

The culvert hydraulic analysis routine in HEC-RAS is similar to that for bridge hydraulics, except that the equations for inlet control in FHWA's HDS-5 (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) are used where applicable to compute the energy losses. HEC-RAS can model many different culvert shapes. However, it does not include a shape corresponding to that of a corrugated aluminum box culvert, which is commonly used in North Carolina. Refer to Section 9.6.2.1.2 for modeling guidance for a corrugated aluminum box culvert. Bottomless ("three-sided") culvert structures typically have either a flat top or arched top waterway opening. An arched-top structure may be modeled as a flat-top structure, ignoring flow area in the arched-top portion of the opening in HEC-RAS runs.

As a one-dimensional flow modeling tool in culvert analysis, HEC-RAS computes the energy grade elevation with the initial assumption that all flow is going through the culvert. The culvert will typically be flowing full and will be submerged before the flow overtops the road. If the computed energy grade elevation is greater than the weir (overtopping) elevation, then weir flow occurs, and HEC-RAS performs an iterative procedure to balance weir and culvert flows to determine the water surface elevation. However, the weir (overtopping) flow may not occur at the roadway location directly above the culvert. Review the roadway profile and floodplain to determine where the minimum elevation for weir flow (overtopping) will occur. For example, a culvert may not be flowing full due to a low-lying bank that allows the water to move away from the culvert, through a ditch and across the road.

9.6.2.1.2 Aluminium Box Culvert (ABC) HEC-RAS Modeling Guidance

Since the Corrugated Metal Box Culvert shape in HEC-RAS does not match the actual area of the ABC when the span and rise of the ABC is placed into the HEC-RAS model, the following methodology should be used to model the ABC:

- ABC's span should be reduced while maintaining the rise until the effective area of the ABC is approximated in the HEC-RAS model. Although this is not considered to be an exact methodology, it should provide a more conservative answer for most situations.
- ABCs should be modeled in HEC-RAS as Corrugated Metal Box Culverts using the Culvert Data Editor as follows:
  - Select Culvert Shape as "Box". Reduce the span as necessary, by trial and error, to provide a culvert area opening that is reflective of the effective open area of the culvert. Use the manufacturer's size chart to determine the actual area of the ABC.
  - If the culvert is buried or altered by other means such as sills/baffles, low flow floodplain benches, etc., determine the effective open area by subtracting out the blockage from the ABC's actual area.

- The rise should be the actual rise of the proposed ABC and should not be adjusted.
- Compare the computed open area of the culvert to the effective open area of the ABC. Chart # should be 16, 17, 18 or 19 depending on the rise/span ratio noted in HDS-5 (FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors) 2012) for the chart.
- Base the rise/span ratio on the actual dimensions of the ABC. Do not use the reduced span length. Scale #1 should be used, based on a 90-degree headwall.
- Complete all other information based on the proposed culvert.

Example:

15’-9” X 8’-0” ABC, buried one foot below the stream bed

Actual culvert area from manufacturer’s chart = 111.8 ft^2, rise/span ratio = 0.5079; use Chart #19, 90-degree headwall, use Scale #1

Effective open area of culvert = Actual Culvert area – blockage

15.75’ bottom span X 1 foot (bury depth) = 15.72 ft^2 blockage

Effective open area = 111.8 ft^2 – 15.72 ft^2 = 96.05 ft^2 , say 96 ft^2

Computed open area in HEC-RAS is modeled as a 15’-9” X 8’-0” Corrugated Metal Box Culvert buried one foot (one foot blocked in Culvert Data Editor) = 110.25 ft^2 (Note effective open area of culvert overestimated by 14 ft^2)

Adjust span length by trial and error to reach effective open area of culvert = 96 ft^2

Use span length = 13.72’, Computed open area in HEC-RAS = 96.04 ft^2 , say 96 ft^2

Therefore, model in HEC-RAS as a 13.72’ X 8’ Corrugated Metal Box Culvert buried 1 foot.

9.6.2.2 Debris Consideration

Reasonably size the culvert opening to provide for debris passage. The general limitation of design headwater depth to not exceed the culvert opening height by more than about 20% has proven to limit debris problems to acceptable levels. Where experience or physical evidence indicates the watercourse will transport excessive debris, special debris controls (e.g. deflectors) may need to be developed or the estimated capacity of the structure reduced to reflect the potential for debris blockage.

9.6.2.3 Evaluation of Outlet Velocity

After a given culvert size has been determined to be adequate for conveyance of the design discharge, it is important to evaluate effects from the outlet velocity and recommend any mitigation measures such as armoring. Use the ten-year (V_{10}) outlet velocity for this comparison. If the partial flow outlet velocity for the ten-year discharge (Q_{10}) exceeds the scour velocity for the receiving stream, placing rip rap or other acceptable outlet protection is required. FHWA HEC-15 (FHWA. R.T. Kilgore and G.K. Cotton (authors) 2005) procedures should be used to determine acceptable flow velocity. Use the greater of tailwater depth or normal flow depth in the culvert to determine the partial flow outlet velocity. In HEC-RAS, use the downstream culvert velocity (Culv Vel DS) for this evaluation.

9.7 Pipe Liner Rehabilitation

The design calculations shall support the acceptability of the proposed rehabilitation system to provide the necessary hydraulic capacity and structural strength to support the anticipated total load and hydrology at the site of rehabilitation, as determined from a review that has been signed and sealed by a Professional Engineer holding a valid license to practice engineering in the State of North Carolina (unless an exception is noted below). Such certification shall cover all design data, supporting calculations, installation plan, and planned rehabilitation materials. The calculations shall indicate that the liner design is for a full structural replacement of a fully deteriorated host pipe.

Refer to NCDOT Pipe Liner Manual on the Hydraulics site for more guidance.

9.8 Construction Sequence

See Chapter 12 Erosion and Sedimentation Control, Section 12.3 regarding the culvert construction sequence plan.

9.9 References

FHWA. 2021. *HY-8 Culvert Hydraulic Analysis Program, version 7.70.* December. Accessed December 2021. https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/index.cfm.

FHWA, J.D.Schall, P.L. Thompson, S.M. Zerges, R.T. Kilgore, J.L. Morris (authors). 2012. "Hydraulic Design of Highway Culverts, Third Edition, Hydraulic Design Series Number 5 (HDS-5)." *Federal Highway Administation, U.S. Department of Transportation.* April. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/12026/hif12026.pdf.

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—. 2021. *HEC-RAS River Analysis System Applications Guide, Version 6.0.* Gary W. Brunner, John C. Warner, Brent C. Wolfe, Steven S. Piper, and Landon Marston.

May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Applications_Guide.pdf.

—. 2021. *HEC-RAS River Analysis System Hydraulic Reference Manual, Version 6.0.* Gary W. Brunner, CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers. May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Reference_Manual.pdf.

—. 2021. *HEC-RAS River Analysis System User's Manual, Version 6.0.* Brunner, Gary W. CEIWR-HEC (author); Institute for Water Resources, Hydrologic Engineering Center (HEC), US Army Corps of Engineers. May. Accessed November 2021. https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_6.0_Users_Manual.pdf.

USACE. Bell, Milo C. (author). 1986. "Fisheries Handbook of Engineering Requirements and Biological Criteria." *US Army Corps of Engineers - Fish Passage Development and Evaluation Program.* Accessed December 2021. http://www.seattle.gov/light/skagit/relicensing/cs/groups/secure/@scl.skagit.team/documents/document/cm9k/ntcw/~edisp/prod570976.pdf.

USDA Forest Service. 2012. "FishXing: Software and Learning Systems for Fish Passage through Culvert (2012-11) version 3." *US Department of Agriculture - Forest Service.* November 08. Accessed December 2021. http://www.fsl.orst.edu/geowater/FX3/help/SwimData/Swim_Speed_Table.htm.

9.10 Additional Documentation

Culvert Survey & Hydraulic Design Report (CSR) Key

Detour Structure Survey & Hydraulic Design Report

Structure Survey Recommendations Form

Pipe Data Sheet

NCDOT Pipe Liner Manual

NCDOT Pipe Material Selection Guide

NCDOT Pipe Liner Special Provision

Grouting Host Pipe Special Provision

Invert Paving Special Provision

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D. Minimum and Maximum Fill Over Pipes

The following tables provide acceptable minimum and maximum earthfill heights over the pipe for several different types of pipe materials.

Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
	Minimum	Maximum	Steel (corrugations)		Aluminum (corrugations)	
			2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
≤18	2	25	16	16	16	16
21	2	25	16	16	16	16
24	2	23	16	16	16	16
	>23	25	16	16	12	16
30	2	18	16	16	14	16
	>18	25	16	16	12	16
36	2	15	16	16	14	16
	>15	25	16	16	12	16
42	2	22	16	16	12	16
	>22	23	16	16	10	16
	>23	24	16	16	---	16
	>24	25	14	16	---	14
48	2	19	16	16	12	16
	>19	20	16	16	10	16
	>20	21	16	16	---	16
	>21	23	14	16	---	14
	>23	25	12	16	---	14
54	2	17	14	16	12	16
	>17	18	14	16	10	16
	>18	20	14	16	---	14
	>20	23	12	16	---	14
	>23	25	12	16	---	12
60	2	16	12	16	10	16
	>16	20	12	16	---	14
	>20	23	12	16	---	12
	>23	25	10	16	---	12
66	2	15	10	16	---	16
	>15	19	10	16	---	14
	>19	22	10	16	---	12
	>22	25	---	16	---	12

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Table 1. Minimum Gauge for Corrugated Metal Pipe (CMP) *(Reference 1)*

Diameter, in.	Acceptable Fill Height, ft		Minimum Gauge CMP			
			Steel (corrugations)		Aluminum (corrugations)	
	Minimum	Maximum	2 2/3 x ½ in.	3 x 1 in.	2 2/3 x ½ in.	3 x 1 in.
72	2	13	10	16	---	16
	>13	17	10	16	---	14
	>17	20	10	16	---	12
	>20	24	---	16	---	10
	>24	25	---	14	---	10
78	2	16	---	16	---	14
	>16	22	---	16	---	12
	>22	25	---	14	---	10

Table 2. Minimum Thickness for Welded Steel Pipe *(Reference 1)*

Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Pipe Wall Thickness, in
	Minimum	Maximum	
≤10	2	30	0.187
12	2	25	0.187
14, 16	2	30	0.25
18	2	23	0.25
	>23	25	0.375
20	2	18	0.25
	>18	25	0.375
24	2	12	0.25
	>12	25	0.375
30	2	8	0.25
	>8	18	0.375
	>18	25	0.5
36	2	6	0.25
	>6	12	0.375
	>12	23	0.5
42	2	5	0.25
	>5	9	0.375
	>9	16	0.5
48	2	4	0.25
	>4	7	0.375
	>7	12	0.5

(210-650-H, Amend. IL66, August 2013)

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Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
4	2	10	40	26
	>10	16	40	21
	>16	21	40	---
	>21	25	80	---
6	2	10	40	26
	>10	12	40	21
	>12	16	80	21
	>16	25	80	---
8	2	10	40	26
	>10	16	80	21
	>16	25	80	---
10	2	8	40	21
	>8	16	80	21
	>16	24	80	---
12 -14	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	22	80	---
16	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	21	80	---
18	2	7	40	26
	>7	10	80	26
	>10	16	80	21
	>16	20	80	---
20	2	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	20	80	---

(210-650-H, Amend. IL66, August 2013)

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Table 3. Minimum Acceptable PVC Pipe *(Reference 1)*

Nominal Pipe Diameter, in	Acceptable Fill Height, ft		Minimum Acceptable PVC Type[1]	
	Minimum	Maximum	Schedule	Standard Dimension Ratio (SDR)
24	2	<3	---	26
	3	6	40	26
	>6	10	80	26
	>10	16	80	21
	>16	19	80	---
30 - 36	2	10	---	26
	>10	16	---	21

[1] Polyvinyl Chloride Pipe, PVC 1120 or PVC 1220, conforming to ASTM D-1785 or ASTM D-2241.

Table 4. Corrugated Plastic Tubing[2] (CPT) *(References 1,2,3)*

Trench Width, in	Max Fill Height, ft	Maximum Diameter CPT (in) per Installation Type	
		Tile Machine	Open Trench
12	any	8"	6"
16	8.4	12"	10"
20	6.8	15"	12"
24	6.0	18"	18"
28	5.6	24"	18"
32	5.3	24"	24"

[2] Single wall corrugated polyethylene (PE) pipe conforming to ASTM F405 or F667

References:

1. USDA-NRCS, National Engineering Handbook, Part 636, Chapter 52, Structural Design of Flexible Conduits.

2. American Society of Agricultural and Biological Engineers. 2008. Standard ASAE EP480. Design of Subsurface Drains in Humid Areas.

3. Spangler, M.G. and R.L. Handy. 1982. Soil Engineering. 4th Edition.

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